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TEST AND EVALUATION OF VEHICLE-MOUNTED SMOKE GRENADE LAUNCHERS (U)

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19 ABSTRACT (Continue on reverse if necessary and identify by block number)

Describe procedures for determining launch angles for vehicle-mounted smoke grenade launchers. These procedures for determining azimuth and elevation launch angles can be applied to any vehicle or system equipped with tube-launched smoke grenade delivery services.

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U.S. ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

AMSTE-RP-702-107
Test Operations Procedure 8-2-094
AD No. 31 March 1993

TEST AND EVALUATION OF VEHICLE-MOUNTED SMOKE GRENADE LAUNCHERS

1. SCOPE

This TOP describes procedures for determining launch angles for vehicle mounted smoke grenade launchers. The resulting measurements can be used to analytically determine, without firing, the dispersion and coverage that would be expected for a given vehicle and launcher combination. Effective screening of a vehicle equipped with smoke grenade launchers is dependent on the ability of the launchers to provide the optimum trajectory for the grenades. These procedures for determining azimuth and elevation launch angles can be applied to any vehicle or system equipped with tube-launched smoke grenade delivery devices.

The azimuth launch angles are determined relative to the launcher, and also relative to the center of the vehicle. In order to determine the azimuth angle relative to the center of the vehicle, a radius of intersection must be defined. This radius of intersection (distance from center of vehicle at which grenades detonate) is used in quantifying angular coverage and spacing of grenades at the time of detonation.

The procedures outlined in this TOP are based on testing performed using an M1A1 Abrams tank equipped with M250 smoke grenade launchers (see ref a and b). The procedures have been generalized for application to any vehicle/smoke grenade launcher configuration. The sample results presented in Appendix A are taken from the Abrams tank testing.

2. FACILITIES AND INSTRUMENTATION

2.1 Facilities.

No unique or specialized facilities are required.

2.2 Instrumentation.

Devices for Measuring	Permissible Error of Measuring Devices
Angular displacement to launcher tube centerline (theodolite)	±10 seconds
Linear displacement to launcher tube centerline	±3 mm
Launcher tube elevation angle (optional)	±0.2 mil
Launcher tube centerline*	±3 mm

*An instrument which is inserted into each grenade launcher tube and used to define two points along the longitudinal centerline of the tube. The theodolite is then used to determine the coordinates of these two points in space. The device can be machined from aluminum stock and consists of two sections: a cylinder section that slides into the launcher tube, and a rodHxection that is marked with two points, A and B, located a distance apart (d) along the longitudinal axis (see fig. 1).

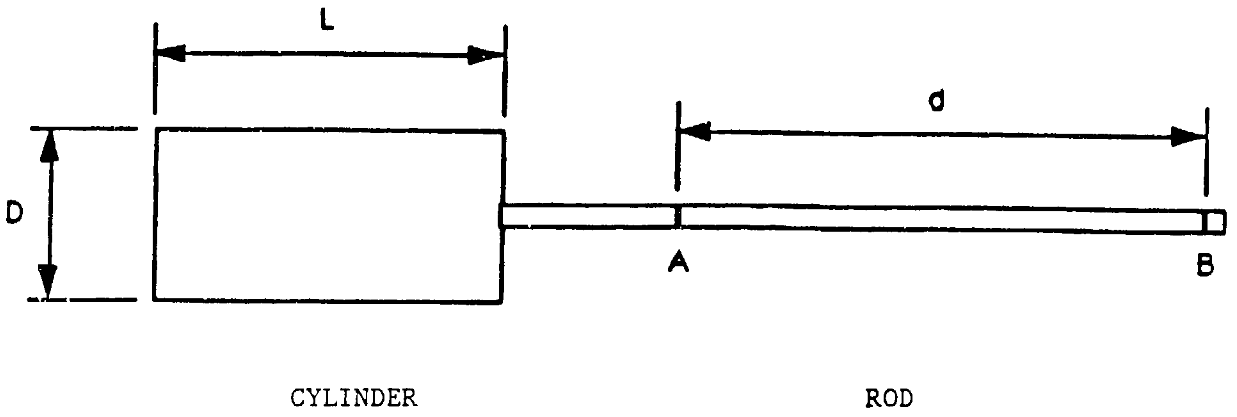


Figure 1. Launch angle measurement device.

Notes: Cylinder diameter D should be sized to provide a snug sliding fit in the grenade launcher tube.
Cylinder length L should be sized to the approximate length of the grenade launcher tube.
The total length of the rod section should be such that points A and B will be readily visible from the theodolite position.
As an example, for the M1A1 Abrams tank testing, D = 6.60 cm, L = 21.59 cm, and d = 60.96 cm.

3. REQUIRED TEST CONDITIONS

3.1 Vehicle Preparation.

Refer to Figure 2 for a graphical depiction of layout and measurement procedures. The equations presented in paragraph 6.1 were formulated based on standard engineering sign conventions.

a. Park the vehicle on level ground.

b. Inspect mounting and condition of the smoke grenade launchers. Ensure that the launchers are secure and mounted using the proper hardware.

c. Determine a point of reference on the vehicle in the horizontal plane that will be the reference for azimuth angles of launch. If possible, this should be the center of the vehicle hull, which is the intersection of the longitudinal (y-axis) and lateral (x-axis) hull centerlines. This will be referred to as point V. Mark the location of point V on the top surface of the vehicle.

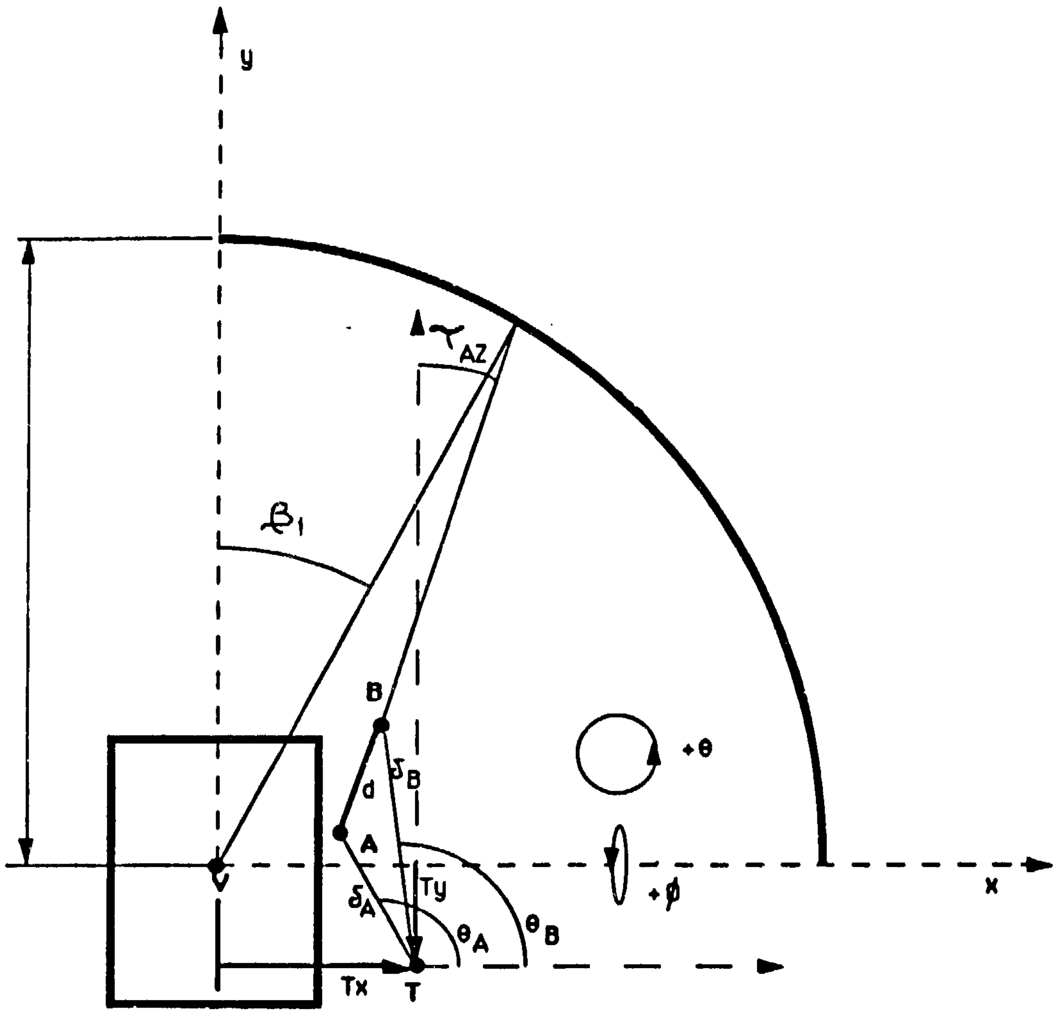


Figure 2. Graphical depiction of layout and measurement procedures (overhead view).

3.2 Instrumentation Setup.

a. If possible, position the theodolite directly over point V. If this is not easily accomplished, position the theodolite at a convenient location on the vehicle or on the ground. Mark the position of the theodolite as point T. Record the coordinates of point T with respect to point V (T_x, T_y).

b. Zero the azimuth and elevation angles of the theodolite. The angle of zero degrees azimuth should be along the positive x-axis if the theodolite is positioned at point V, or along an axis parallel to the positive x-axis if the theodolite is positioned at point T. Establish the angle of zero degrees elevation in a plane parallel to the horizontal (xy) plane.

c. Insert measurement device into a smoke grenade launcher tube.

4. TEST PROCEDURES

a. Using the theodolite, turn an azimuth angle θ_A about the z-axis (in the horizontal plane) and an elevation angle ϕ_A about the x-axis (in the vertical plane) to point A on the measurement device. Record angles θ_A and ϕ_A.

b. Zero the theodolite as in paragraph 3.2b.

c. Repeat step 4a to point B on the measurement device, recording the angles θ_B and ϕ_B.

d. Measure and record the distance from the center of rotation of the theodolite to points A and B on the measurement device (δ_A and δ_B).

e. Repeat steps 4a through 4e for all grenade launcher tubes of interest.

5. DATA REQUIRED

The following data are required from paragraphs 3 and 4 for determination of launch angles:

a. Location of reference point on vehicle (point V).

b. Location of theodolite position (point T) with respect to point V.

c. Distance between points A and B on measurement device (d).

d. Spherical coordinates of points A and B with respect to point T (θ_A, ϕ_A, δ_A, θ_B, ϕ_B, δ_B).

6. PRESENTATION OF DATA.

6.1 Determination of Launch Angles.

a. Cartesian coordinates of points A and B. The cartesian coordinates of points A and B in the coordinate system with origin at point T are given by:

$$x_T = \delta\cos\phi\cos\theta$$
$$y_T = \delta\cos\phi\sin\theta$$
$$z_T = \delta\cos(90-\phi) = \delta\sin\phi$$

b. Distance between points A and B. The distance between points A and B is:

$$d = [(x_{TB} - x_{TA})^2 + (y_{TB} - y_{TA})^2 + (z_{TB} - z_{TA})^2]^{1/2}$$

This should be verified by taking a physical measurement of the distance between points A and B on the measurement device.

c. Elevation angle. The elevation angle, τ_{el}, of each grenade launcher tube is the angle bounded by the horizontal plane and the line segment AB, and can be determined from the following expression:

$$\tau_{el} = \sin^{-1} \frac{z_{TB} - z_{TA}}{d}$$

This can be verified using a gunner's quadrant placed on the rod section of the measurement device installed in the tube.

d. Azimuth angle. The azimuth angle, τ_{az}, of each grenade launcher tube is the angle bounded by the y-axis and the projection of the line segment AB on the horizontal plane, and can be determined from the following expression:

$$\tau_{az} = \tan^{-1} \frac{x_{TB} - x_{TA}}{y_{TB} - y_{TA}}$$

e. Azimuth angle of intersection. The azimuth angle of intersection of the grenade with respect to the vehicle center line (y-axis) at a desired radius R from the hull origin (point V) can be determined using the following steps:

(1) Determine the coordinates of points A and B with respect to the vehicle origin (point V).

$$x_{VA} = x_{TA} + T_x \qquad y_{VA} = y_{TA} + T_y$$

$$x_{VB} = x_{TB} + T_x \qquad y_{VB} = y_{TB} + T_y$$

(2) The equation of the line through points A and B in the coordinate system with origin at point V is given by:

$$y = mx + b$$

where:

$$m = \frac{y_{VB} - y_{VA}}{x_{VB} - x_{VA}}$$

and

$$b = \frac{x_{VB}y_{VA} - y_{VB}x_{VA}}{x_{VB} - x_{VA}}$$

(3) The point of intersection of the line through points A and B and the circle of radius R can be determined by the simultaneous solution of the two equations

$$y = mx + b$$

and

$$x^2 + y^2 = R^2$$

which results in

$$x_i = \frac{-2mb \pm (4m^2b^2 - 4(1+m^2)\ (b^2-R^2))^{1/2}}{2(1+m^2)}$$

$$yi = mx_i + b$$

(4) The angle at which the grenade crosses the circle of radius R is the azimuth angle of intersection and is given by:

$$\beta_i = \tan^{-1} \frac{x_i}{y_i}$$

6.2 Presentation of Results.

Present results in both tabular and graphical formats. Results should include:

a. Required or specified design values for azimuth and elevation angles compared to measured results. Angles should be presented for each launcher tube of each grenade launcher assembly both relative to the launcher and relative to the vehicle reference point.

b. Required or specified design values for azimuth spacing of grenades relative to the vehicle reference point, compared to measured results. Coverage of the vehicle can be portrayed using this method taking into account all grenades launched at a specified time (salvo).

Appendix A contains sample formats for results presentation.

Recommended changes of this publication should be forwarded to Commander, U.S. Army Test and Evaluation Command, ATTN: AMSTE-TC-D, Aberdeen Proving Ground, MD 21005-5055. Technical information can be obtained from the preparing activity: Commander, U.S. Army Combat Systems Test Activity, ATTN: STECS-DA-ID, Aberdeen Proving Ground, MD 21005-5059. Additional copies are available from the Defense Technical Information Center, Cameron Station, Alexandria, VA 22304-6145. This document is identified by the accession number (AD No.) printed on the first page.

APPENDIX A

SAMPLE FORMATS FOR PRESENTATION OF RESULTS

SMOKE GRENADE LAUNCHER AZIMUTH AND ELEVATION ANGLES

MEASUREMENTS TAKEN USING LAUNCHER AS ORIGIN

	DESIGN VALUES AZIMUTH (DEGREES)	MEASURED VALUES AZIMUTH (DEGREES)		DESIGN VS MEASURED DIFFERENCE AZIMUTH (DEGREES)	
TUBE #	BOTH SIDES	RIGHT SIDE	LEFT SIDE	RIGHT SIDE	LEFT SIDE
1	0.00	-0.54	-0.70	0.54	0.70
2	10.94	10.44	10.10	0.50	0.84
3	22.15	20.64	21.33	1.51	0.82
4	33.44	32.60	32.87	0.84	0.57
5	44.65	43.54	44.21	1.11	0.44
6	55.59	54.51	55.28	1.08	0.31
AVERAGE				0.93	0.61
STD DEVIATION				0.38	0.21

	DESIGN VALUES ELEVATION (DEGREES)	MEASURED VALUES ELEVATION (DEGREES)		DESIGN VS MEASURED DIFFERENCE ELEVATION (DEGREES)	
TUBE #	BOTH SIDES	RIGHT SIDE	LEFT SIDE	RIGHT SIDE	LEFT SIDE
1	25.00	24.31	25.37	0.69	-0.37
2	26.77	26.36	27.50	0.41	-0.73
3	27.68	28.16	28.61	-0.48	-0.93
4	27.68	27.60	28.59	0.08	-0.91
5	26.77	26.98	27.73	-0.21	-0.96
6	25.00	25.28	26.02	-0.28	-1.02
AVERAGE				0.04	-0.82
STD DEVIATION				0.45	0.24

Figure A-1. Sample tabular results using launcher as origin.

SMOKE GRENADE LAUNCHER AZIMUTH ANGLES

MEASUREMENTS REFERENCED TO CENTER OF VEHICLE AS ORIGIN
R = 30 M (98.4 ft)

TUBE #	DESIGN VALUES AZIMUTH (DEGREES)	DESIGN VALUES REFERENCED TO CENTER OF VEHICLE AZIMUTH (DEGREES)		MEASURED VALUES REFERENCED TO CENTER OF VEHICLE AZIMUTH (DEGREES)		DESIGN VS MEASURED DIFFERENCE REFERENCED TO CENTER OF VEHICLE AZIMUTH (DEGREES)	
		RIGHT SIDE	LEFT SIDE	RIGHT SIDE	LEFT SIDE	RIGHT SIDE	LEFT SIDE
1	0.00	2.91	2.74	2.38	2.22	0.53	0.52
2	10.94	13.69	13.69	13.20	12.86	0.49	0.83
3	22.15	24.63	24.63	23.16	23.83	1.47	0.80
4	33.44	35.55	35.55	34.74	35.00	0.81	0.55
5	44.65	46.31	46.31	45.25	45.89	1.06	0.42
6	55.59	56.75	56.75	55.73	56.46	1.02	0.29
AVERAGE						0.90	0.57
STD DEVIATION						0.37	0.21

Figure A-2. Sample tabular results using vehicle as origin.

SMOKE GRENADE LAUNCHER TUBE TO TUBE ANGULAR SPACING IN AZIMUTH

FROM MEASUREMENT TAKEN USING LAUNCHER AS ORIGIN

R = 30 m (98.4 ft)

TUBE #	DESIGN VALUES AZIMUTH SPACING (DEGREES)	MEASURED AZIMUTH SPACING (DEGREES) RIGHT SIDE	LEFT SIDE
1 to 2	10.00	10.98	10.80
2 to 3	10.00	10.20	11.23
3 to 4	10.00	11.96	11.54
4 to 5	10.00	10.94	11.34
5 to 6	10.00	10.97	11.07
AVERAGE	10.00	11.01	11.20
STD DEVIATION	0.00	0.63	0.28

Figure A-3. Sample tabular results of angular spacing.

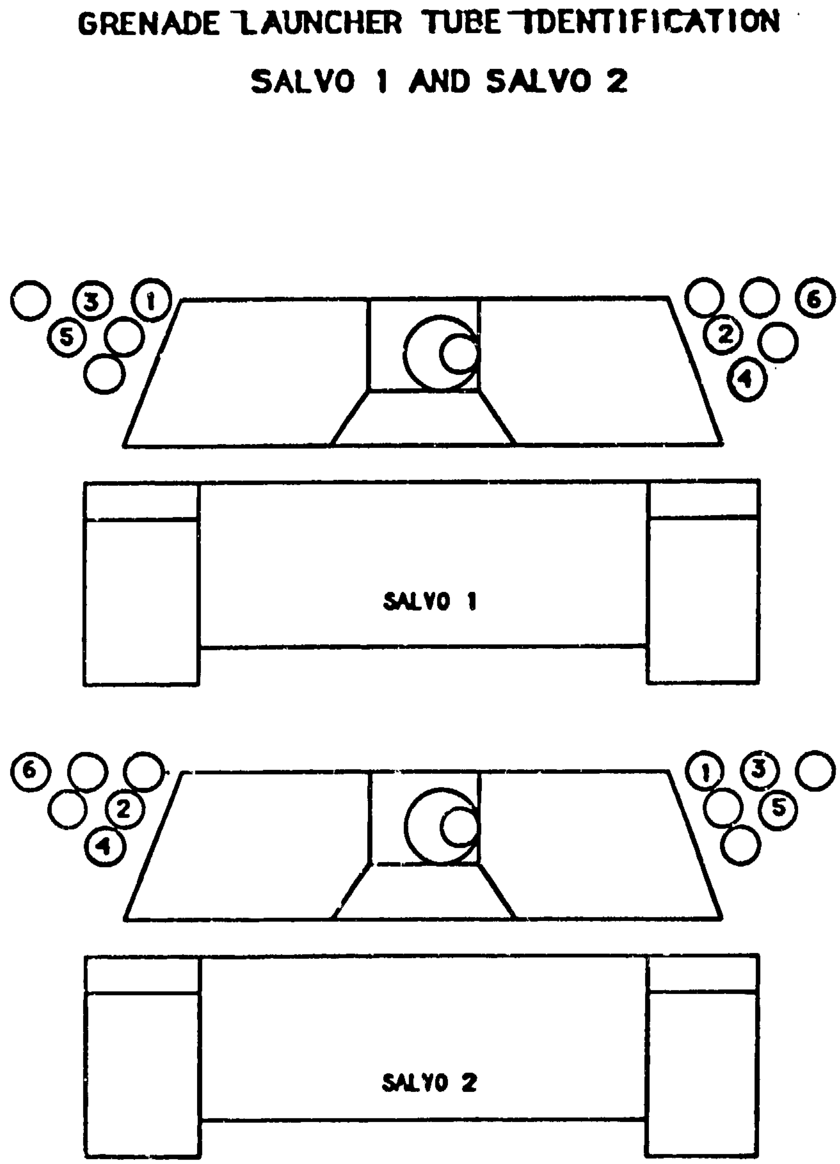


Figure A-4. Sample graphical representation of grenade launcher tube identification.

SMOKE GRENADE LAUNCHER SALVO 1 ARRAY

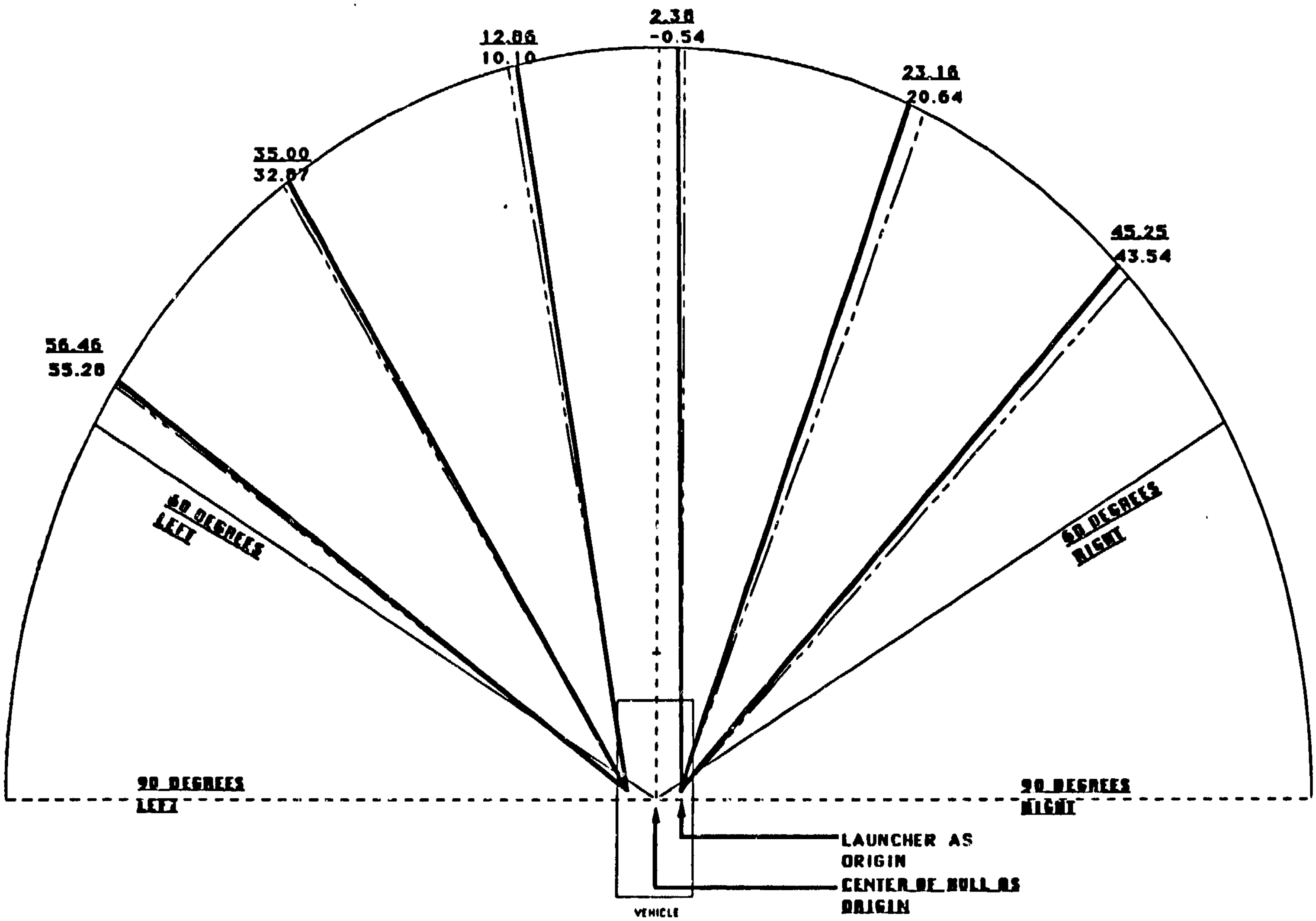


Figure A-5. Sample graphical representation of launcher azimuth angles.

APPENDIX B

DERVIATION OF EQUATIONS

Using fiure 2 as a reference, the cartesian coordinates of points A and B in the coordinate system with origin at point T can be determined by first projecting δ ($_A$ and $_B$) onto the horizontal plane:

Projection of δ onto horizontal plane = $\delta \cos\phi$.

The projections of $\delta \cos\phi$ onto the x and y axes are then the x and y coordinates, respectively, of the point in question (A or B):

$$x_T = \delta \cos\phi \cos\theta$$
$$y_T = \delta \cos\phi \sin\theta.$$

The z coordinate is given by the projection of δ onto the z axis:

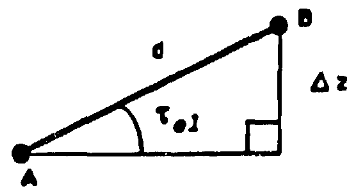
$$z_T = \delta \cos(90-\phi) = \delta \sin\phi.$$

The distance between points A and B is determined by taking the square root of the sum of the squares of the length of the projections on each plane:

$$d = [(x_{TB} - x_{TA})^2 + (y_{TB} - y_{TA})_2 + (z_{TB} - z_{TA})^2]^{1/2}$$

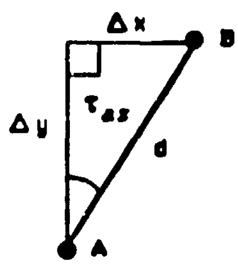
The elevation angle of each grenade launcher tube is the angle bounded by the horizontal plane and the line segment AB:

$$\tau_{el} = \sin^{-1} \frac{z_{TB} - z_{TA}}{d}$$



The azimuth angle of each grenade launcher tube is the angle bounded by the y-axis and the projection of the line segment AB on the horizontal plane:

$$\tau_{az} = \tan^{-1} \frac{x_{TB} - x_{TA}}{y_{TB} - y_{TA}}$$



The azimuth angle of intersection between the trajectory of a fired grenade and the longitudinal axis of the vehicle at a given radius R from point V, can be determined by first translating the coordinates of points A and B from the theodolite coordinate system to the vehicle coordinate system:

$$x_V = x_T + T_x$$

$$y_V = y_T + T_y.$$

Knowing the slope and the y-intercept of the line through points A and B, the equation of this line is given by:

$$y = mx + b,$$

where the slope is

$$m = \frac{y_{VB} - y_{VA}}{x_{VB} - x_{VA}}$$

and the y-intercept is

$$b = \frac{x_{VB}y_{VA} - y_{VB}x_{VA}}{x_{VB} - x_{VA}}.$$

The equation of the circle with radius R and origin at point V is

$$x^2 + y^2 = R^2.$$

Simultaneous solution of the equation of the line and the equation of the circle results in the coordinates of the point of intersection as being:

$$x_i = \frac{-2mb\ (+-)\ (4m^2b^2 - 4(1 + m^2)(b^2 - R^2))^{1/2}}{2(1 + m^2)}$$

$$y_i = mx_i + b.$$

The angle between the point of intersection and the longitudinal axis of the vehicle is then given by:

$$\beta_i = \tan^{-1}\frac{x_i}{y_i}.$$

APPENDIX C

REFERENCES

For Information Only

a. Compton, Louise D., Final Report, Functional Evaluation of New Adapter Assemblies of the New Lightweight 8-Tube (2-M257 Grenade Launchers Mounted on Adapter Assemblies) Smoke Grenade Launcher (SGL) for Abrams Family of Tanks, TECOM Project No. 1-VC-080-1A1-102. U.S. Army Combat Systems Test Activity, Report No. USACSTA-7010, August 1990.

b. Compton, Louise D., Addendum 1 to Final Report, Functional Evaluation of New Adapter Assemblies of the New Lightweight 8-Tube (2-M257 Grenade Launchers Mounted on Adapter Assemblies) Smoke Grenade Launcher (SGL) for Abrams Family of Tanks, TECOM No. 1-VC-080-1A1-129. U.S. Army Combat Systems Test Activity, Report No. USACSTA-7010, November 1990.